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Incoherent scattering of 59.54 keV gamma rays for some rare earth elements at low photon momentum transfers

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Abstract

Incoherent scattering functions $S(x, Z)$ for six rare earth elements were evaluated from accurately measured whole atom differential incoherent scattering cross sections for 59.54 keV γ-rays scattered at 30°, 45°, 60° and 90° scattering angles corresponding to 1.24, 1.84, 2.40 and 3.39 Å^{-1} photon momentum transfers. Our results for $S(x, Z)$ are the first for these rare earth elements.

Keywords: Reflection geometry; Incoherent scattering functions; K-edge effects

1. Introduction

Incoherent scattering is one of the three major processes of interaction of γ-rays with matter at low and intermediate photon energies. Although the Klein–Nishina formalism (Klein and Nishina, 1929) describes incoherent scattering of photons by free and stationary electrons, deviations from the Klein–Nishina theory occur at low energies because of the possible emission of an additional photon and the radiative correction associated with the emission of virtual photons (Hubbell, 1983). The binding effect of the atomic electrons has been taken into account (Hubbell, 1969) by including a multiplicative correction factor known as the incoherent scattering function $S(x, Z)$.

A precise verification of the $S(x, Z)$ formalism requires accurate experimental data on whole atom differential incoherent scattering cross sections. While such experimental data are available at high photon energies and at intermediate and large momentum transfer values, experimental data is lacking for important elements in the rare earth region for low momentum transfer values. We have therefore carried out an experimental study to test the $S(x, Z)$ formalism at low momentum transfer values. This was done by accurately measuring whole atom differential incoherent scattering cross sections for 59.54 keV γ-rays scattered at 30°, 45°, 60° and 90° angles by the rare earth elemental foils. The $S(x, Z)$ values were evaluated from the measured cross sections and were compared with Hartree–Fock and Thomas–Fermi atomic model predictions. Possible conclusions are drawn on electron binding and K-edge effects.

2. Experimental details

The geometry and shielding arrangement of the experimental setup employed in the present work is given elsewhere (Pinto et al., 1994). The scattering experiments were conducted in a reflection geometry arrangement (Kane, 1992) by allowing 59.54 keV γ-rays from 300 mCi ^{241}Am to undergo incoherent scattering by the scatterer foils. Thin elemental foils of six rare earth elements Pr, Sm, Gd, Dy, Ho and Yb were used as scatterers. The areal density of these foils ranged from 0.017 to 0.032 g/cm^2. A 6 cc hyper pure germanium detector was used to detect the scattered γ-rays and the spectra were recorded using a PC based 4 K analyzer. The area under the incoherent peak was evaluated using a computer software package by fitting a Gaussian function after subtracting the background. The cross

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sections and the $S(x, Z)$ values were evaluated using Al as a standard target and employing the relations used in our earlier work (Pinto et al., 1994).

3. Results and discussions

Cross sections obtained in the present work, the $S(x, Z)$ values evaluated from the cross sections and a comparison with theory are given in Table 1.

Data in Table 1 reveal that the measured cross sections show increased deviations from Klein–Nishina results as Z increases, clearly suggesting significant electron bonding effects with decreasing momentum transfer. This is the case for all four momentum transfer values investigated. This is consistent with our previous results (Pinto et al., 1990, 1994) which indicate large electron binding effects for heavy elements, the effect becoming stronger as the photon energy decreases.

Our results for $S(x, Z)$ show better agreement with non-relativistic Hartree–Fock (NRHF) theory. This is particularly clear in our measured cross sections at a scattering angle of 45° ($x = 1.84\,\text{Å}^{-1}$). We further observe that our $S(x, Z)$ results show better agreement with NRHF theory than with Thomas–Fermi (TF) model predictions. Similar findings have been reported at intermediate and large momentum transfer values (Shivananda et al., 1984).

4. Conclusions

Cross sections measured in the present work constitute the first report for the given targets and parameters and fill the existing gap in cross section data in the region $59 \leqslant Z \leqslant 70$ for six rare earth elements at 59.54 keV. The cross section results show significant electron binding effects, the effects becoming significant as Z increases. The analysis shows that $S(x, Z)$ formalism based on NRHF theory is qualitatively better than the TF model in predicting $S(x, Z)$ values.

Table 1
Measured cross sections and $S(x, Z)$ values

El	Incoh. cross sections (b/atom)		Incoh. scatt. functions $S(x, Z)$		
	Present work	KN theory	Present work	HF model	TF model
		At $x = 1.242\,\text{Å}^{-1}$ ($\theta = 30°$)			
Pr	2.0 ± 0.1	3.975	30.0 ± 1.5	37.17	38.47
Sm	2.1 ± 0.1	4.177	29.5 ± 1.5	38.40	38.76
Gd	2.2 ± 0.1	4.312	29.8 ± 1.5	39.36	40.00
Dy	—	—	—	—	—
Ho	2.2 ± 0.1	4.514	30.0 ± 1.5	40.20	40.93
Yb	2.2 ± 0.1	4.716	30.7 ± 1.5	41.30	42.99
		At $x = 1.840\,\text{Å}^{-1}$ ($\theta = 45°$)			
Pr	2.3 ± 0.1	3.288	40.4 ± 2.0	43.07	44.26
Sm	2.4 ± 0.1	3.456	42.3 ± 2.1	44.95	45.88
Gd	2.4 ± 0.1	3.567	43.4 ± 2.2	46.08	47.00
Dy	—	—	—	—	—
Ho	—	—	—	—	—
Yb	2.5 ± 0.1	3.901	44.7 ± 2.2	49.00	49.70
		At $x = 2.40\,\text{Å}^{-1}$ ($\theta = 60°$)			
Pr	1.9 ± 0.1	2.622	41.9 ± 2.1	47.20	49.60
Sm	1.9 ± 0.1	2.755	43.5 ± 2.2	48.98	50.80
Gd	1.9 ± 0.1	2.844	44.3 ± 2.2	50.24	51.81
Dy	—	—	—	—	—
Ho	—	—	—	—	—
Yb	2.1 ± 0.1	3.110	47.4 ± 2.4	54.25	56.60
		At $x = 3.39\,\text{Å}^{-1}$ ($\theta = 90°$)			
Pr	1.6 ± 0.1	1.902	50.1 ± 2.5	51.68	51.92
Sm	1.7 ± 0.1	1.999	51.9 ± 2.6	53.38	53.94
Gd	1.7 ± 0.1	2.063	53.4 ± 2.7	55.04	55.68
Dy	1.8 ± 0.1	2.128	55.1 ± 2.8	56.50	57.09
Ho	—	—	—	—	—
Yb	—	—	—	—	—

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References

Hubbell, J.H., 1969. Photon cross sections, attenuation coefficients and energy absorption coefficients from 10 keV to 100 GeV. National Standard Reference Data Series-NSRDS-NBS-29.

Hubbell, J.H., 1983. Photon attenuation coefficients and cross section data 100 eV–100 GeV. Current status and prospects. Proceedings of the International Symposium on Radiation Physics, ISRP-2, Universiti Sains Malaysia, 15–22.

Kane, P.P., 1992. Inelastic scattering of X-rays and γ-rays by inner shell electrons. Phys. Reports 218, 67–139.

Klein, O., Nishina, Y., 1929. Uber die Streuung von strahlung durch freie elektronen nach der neaen relativistischen Quatendynamik von Dirac. Z. Phys. 52, 853–868.

Pinto, G., Govinda Nayak, N., Balakrishna, K.M., Siddappa, K., 1994. Verification of incoherent scattering functions at intermediate photon momentum transer. J. Phys. B 27, 1683–1691.

Pinto, G., Govinda Nayak, N., Balakrishna, K.M., Lingappa, N., Siddappa, K., 1990. Incoherent scattering of 279.2 keV γ-rays by medium and heavy elements. J. Phys. B 23, 3759–3765.

Shivananda, A.H., Gopal, S., Sanjeevaiah, B., 1984. Differential incoherent scattering cross sections of 661.5 keV γ-rays in some gaseous, liquid and solid elements. Phys. Rev. A 30, 2468–2471.